A CANADIAN ARCTIC RESOURCE AIR TRANSPORT SYSTEM

by

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Pages 1 thru 9, plus illus.

Preprint of a paper to be presented to 23rd Annual Pet. Society Tech. Meeting, May 17-19, 1972- Calgary

Preprint of a paper to be presented to the
Twenty-Third Annual Petroleum Society Technical Meeting
to be held in Calgary, Alberta, May 17 - 19, 1972

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ABSTRACT

Discovery of oil and gas in the Arctic may pose the greatest transportation challenge of our time. Airlifting the oil out of the Arctic might be preferable to fighting the environment every foot of the way along the surface. There are several conditions for competitive costs. The airplane should be large to take advantage of economies of scale, a very high utilization of expensive elements of the system must be achieved, and perhaps the cargo should be transferred to a surface mode once it reaches a more temperate climate. Conceptual design studies and preliminary economic analyses indicate an airlift system may provide competitive transportation for oil, natural gas or other resources in some Arctic situations.

THE CHALLENGE

The transportation challenge posed by the discovery of oil and gas in the Arctic is almost unique in history. The challenge comes from a combination of factors: the large quantities of valuable oil and gas, the ready and eager markets, the hostile nature of the weather and terrain between newly discovered fields and the markets, and increased emphasis by conservationists and world governments on environment. The difficulties anticipated for traditional modes of transportation in the Arctic may be offset to a large degree by application of the pool of technology accumulated by the aerospace industry in meeting other challenges including successfully dealing with the much harsher environment of space. These factors suggest an opportunity for a novel, or at least an unconventional solution. However, the suggestion that airlift may be the most attractive and economical solution requires some explanation. Several simple principles must be combined to understand the logic of the concept. Perhaps a review of the history of the concept is the best way to introduce these underlying principles.

BEGINNINGS OF THE CONCEPT

The history of Boeing interest in the transportation challenge posed by discovery of Arctic oil and gas goes back to late in the summer of 1969. An old friend stopped in Seattle on his way back to

Houston from Prudhoe Bay. He had looked over the North Slope first hand in preparation for making his company's bid in the Alaskan lease auction. He was convinced that getting the oil out would be a major problem and half-seriously asked about the possibilities of airlift. It took only a few minutes minutes and a couple of old envelope backs to convert from current air freight rates to costs per barrel delivered by air to a refinery gate at a major market. The answer was many times the posted price. This was only the first time that I found how easy it is to "prove" that moving oil by air isn't practical. Since then, I've seen it done hundreds of times.

By the end of 1969, my friend's company held lease rights on part of the slope. Meanwhile, I had consulted everyone willing to talk and we had reviewed most of the conventional air freight approaches studied by Boeing and others over many years. Each time it was easy to "prove" crude oil airlift wasn't practical.

My friend understood the U. S. National Environmental Policy Act of 1969 long before most people did, and wisely increased the pressure on me. By the time the injunctions were issued against the Trans Alaskan Pipeline System in April of 1970, a small group at Boeing was finally beginning to understand the problems and find the fundamental conditions for resource airlift to be feasible.

SHORT-HAUL AND COMPLEMENTARY SYSTEMS

For instance, in trying to fly the crude all the way to California, we were overflying good ice-free ports in southern Alaska. Making a transfer from air to ship lowered the total transportation cost by a factor of four or five, but still left the cost of transportation alone far above the best possible sale price. However, the basic idea of using two methods or modes of transportation to complement each other appears sound and has been retained.

UTILIZATION

The next discovery led us past a mental barrier of our own making. It is axiomatic that an airplane is too expensive to be left idle. But we often used typical airline or military utilization factors in our early studies. We incorrectly assumed these factors represented some inherent limits on airplane operations.

They don't at all! Airline utilization factors primarily reflect the facts that most people are willing to fly only at certain times of the day and many are willing only at certain times of the year. (In the military, either peace-time budgets or war-time tactical considerations are primary factors that sometimes keep utilizations low.) Without such constraints, and with a constant, around the clock flow of cargo, it appeared that utilizations in the range of 18 to 20 flight hours per day might be achieved. Military mobilization exercises and other data support this belief.

Operations at these high utilization factors changed many assumptions and many ground rules and "old reliable" formulas for estimating costs could no longer be applied. Recalculating operational costs at high average utilizations indicated that oil might be airlifted 500 to 600 miles with existing airplanes for something less than the posted price per barrel.

USE OF EXISTING AIRPLANES

The 747 offered the best economic efficiency of any in-service airplane so we examined the 747 for use as a crude oil tanker in short-haul, high utilization operations. We considered a 747F - the cargo version - modified to include oil tanks. Because of such short distances, the large main fuel tanks in the 747F wings would not be needed for fuel. The normal fuel load could largely be replaced with payload in addition to that carried in the body. This gave significant increase in cargo capacity and hence in productivity.

Special new airports or air terminals would have to be built for such a system to operate in the Arctic. They did not have to handle passengers like most existing airports, so we gained the freedom to engineer the total system. Concepts for eliminating airplane taxi time and reducing maintenance and support costs by novel terminal designs were developed.

By mid-summer 1970 we believed that all of these ideas applied to a modified 747F might produce a system that could airlift oil 500 to 600 nautical miles for \$1. 50 to \$2. 00 per barrel. This was still too high except for certain special situations in the opinion of oil company people. Remember that optimism about early starts for Arctic pipelines was still high then and cost estimates for them were still low. The commercial 747 tanker concept was put back on the shelf.

NEW DESIGNS

As we worked with ideas for modifying the 747, we were struck by several facts. The basic high speed capability was of little significance on a 500 mile trip and, although its size was large in terms of passengers, the 747 was small in terms of large oil reservoirs. We also found that much of the flexibility and versatility built into the 747 for diverse, world-wide service was of no use in our tanker system.

Boeing therefore launched a conceptual study of a large all new design airplane, primarily in search of the economies of scale, but also seeking simplicity, reliability and durability to reduce both initial and maintenance costs.

PAYLOAD, ENGINES AND GEOMETRY

One of the most innovative and experienced designers in the business undertook these studies. He expanded the idea of putting payload in the wings to the point of moving all the payload to the wings. This distributed the payload to where the lift was generated and where it could easily be supported by the landing gear when on the ground. He assessed the state of the jet engine art and decided to use one of the three largest existing engines to avoid spending the large amount required for new engine development. Perhaps most significant, he decided that use of the simplest possible geometry would solve many difficult landing gear problems and contribute a great deal to limiting initial costs.

EXTERNAL CARRIAGE OF CARGO

A Canadian group had examined our 747 oil airlift studies and seen some of the new designs. They asked if the new design might haul ore and mineral slurries as well as crude oil. This led to the concept of external carriage of the cargo in removable containers or pods mounted on the wings. The removable cargo pod idea not only permitted much more rapid turnarounds but permitted design or special containers for many kinds of cargo without compromise to the basic airplane. It is the same principle as the locomotive and rail car and is potentially a major breakthrough in airlift concepts. Many other novel concepts were introduced and old concepts revised, primarily to reduce initial and operating costs. The idea of using methane or propane as alternative fuels was introduced to help reduce engine maintenance and improve engine life as well as to help solve potential fuel availability problems.

It is the combined application of all of the principles discussed above in a single integrated system design that leads to the promise of an economically attractive Arctic resource airlift.

SIZE

The size chosen for the new designs was somewhat arbitrary. One requirement was a system flow capability equal to that of a 48" crude pipeline. Eight-, ten- and twelve-engine sizes were all considered. In the initial studies, economy seemed to improve as the size increased; no unique problems appeared. Initial investment, utilization rate, maintenance and crew costs all favored a large size. The twelve-engine size provided a comfortable time interval between landings (an economic value in case of emergency) so it was chosen for more detailed study.

THE PRESENT CONCEPT

THE AIRPLANE

A general view of the present airplane concept is shown in Figure 1. Remember that high airspeed becomes less and less significant to system economics as trip distances become shorter. At the 500 to 1000 mile distances under consideration for the Arctic, the higher cruise airspeeds that can be achieved by a sweptback wing do not appear to be worthwhile. Limiting speed to the neighborhood of Mach 0.65 or about 400 knots permits a straight, relatively thick wing which matches the requirement to have the landing gear in a straight line to permit take-off rotation. This also leads to high structural efficiency and great simplicity when compared to other contemporary designs. The rectangular wing also results in major savings in acquisition and maintenance costs by reducing the number of different components required. All landing gears, nacelles, struts, wing connections and control surfaces can be identical.

The key dimensions are shown in Figure 2. The wing-mounted pods carry all of the cargo and are 26 feet in diameter. This diameter can accommodate the cross-section of four 8' x 8' standard cargo containers. This view also shows how the landing gears are distributed laterally to provide support for the large loads. Equalized gear loading for uneven runways, structural deflections and wing low landings can be obtained by hydraulically interconnecting the oleo struts.

Other characteristics not shown include: wing area, 32,560 square feet; operating weight empty, 985,000 pounds; maximum payload, 2,320,000 pounds; and maximum gross weight for take-off, 3,550,000 pounds. This payload is about 8,100 barrels of the 40° A.P.I. gravity oil we have used as a base point.

The technical results of distributing the large inertia loads along the wing are shown in Figure 3. Fuel, engines and payload are supported directly by the airloads to minimize wing bending moments. Placing the landing gears under these heavy masses minimizes ground operation bending moments.

The wide landing gear tread precludes cargo operations from most existing, narrow runways. This is acceptable because the airplane is intended to operate between a few dedicated bases. Ferry

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THE PRESENT CONCEPT

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missions to other bases can be accommodated by leaving the outboard gears retracted when there is no payload. Runway length requirements are comparable to those of existing commercial jets.

CARGO HANDLING

The idea of carrying the payload in detachable, preloaded pods was originally conceived to speed ground turnarounds and to help accommodate alternative cargos. See Figure 4. The pod on each wing consists of two identical containers which are given the proper aerodynamic shape by each container having a detachable end fairing and by installing fixed fairings above and below the wing box to match the container cross-section. The end fairings are common to all containers (oil, LNG, ore) and can also be attached directly to the wing. Figure 5 shows an unloading sequence for one concept for the rapid handling of the payload containers at a major base. The aircraft has come to a stop in a predetermined position and the attachment locks have been released. The transporter on rails rolls into position (A). The transporter rotates the container around the upper suspension fork (B). The lifting mechanism of the transporter lifts the container out of the upper fork, completing separation from the aircraft (C). The transporter with the container rolls away toward the ground cargo transfer station (D). Another transporter then moves in with an empty container and goes through the reverse sequence. Operationally, all four containers would probably be lifted or lowered simultaneously to balance loads on the wing.

TERMINALS

Rapid turnaround is the basic criterion for design of the major terminals. The three-runway system shown in Figure 6 is an almost fully developed example of one concept which attempts to achieve this objective.

The scheme is based on the idea that a loaded airplane can land into the wind on an outer runway and brake to a stop in a container exchange station, go through the exchange process described above, and immediately start to accelerate for a downwind take-off on the center runway. On rare occasions, the winds might be so strong that the airplane would have to taxi the length of the center runway to take-off into the wind on an outer runway. This infrequent loss of efficiency would have to be considered in economic studies. Under almost all wind conditions, however, the downwind take-off would be at least as safe as the normal upwind landing because of the very great weight difference.

At the other terminal, the unloaded airplane would land downwind and take-off upwind. The system for transfer of the cargo between the containers and the gathering system or the complementary ground system is centralized to minimize distances and below runway level to eliminate interference with air traffic. Eight positions are available for each of the container transfer stations (only one end would operate for any given wind) to provide economical pumping rates. Development of this terminal for much higher traffic rates might be done by adding two more container exchange stations at each end in the taxi by-pass areas. Terminal and ground equipment designs are major, critical elements of the resource transport system.

COSTS FOR OIL AND ORES

Our preliminary economic analyses suggest that further study and development could be very worthwhile. The two sets of cost examples shown in Figure 7 were computed using a modified Rand cost model. The higher cost estimates were obtained by extrapolating from experience gained on commercial and military programs and by adjusting for the obvious differences between this and past systems.

The lower cost estimate calculations were made similarly, but assumed that manufacturing methods and operating procedures would be geared specifically for this system and that the resulting costs would be significantly lower.

Both estimates involve the same extremely conservative assumptions on fleet attrition, but they differ in three major respects. The minimum number assumes each airplane will fly just over 20 hours per day on the average and is thus based on 37 airplanes operating. It includes an assumed average cost per airplane of approximately 70 million and a total facilities cost of $430 million. The higher estimate is based on the assumptions of 15 flight hours per day average, a fleet of 51 airplanes operating and an average airplane cost of $84 million. The total facilities cost in this case was taken as $683 million.

Transportation fuel cost differences between petroleum and mineral resources recognize the potential basic difference in fuel availability. Fuel based on wellhead prices could be available in the case of petroleum or LNG (liquid natural gas) transport. It was assumed that fuel for mineral transport would have to be purchased at a regular market price.

COSTS FOR LIQUEFIED NATURAL GAS

Costs to carry LNG can also be derived from these estimates. If we assume a 5% loss of payload because of increased tank weight due to insulation and pressurization requirements, then the cost to move LNG would be 2.2¢ per MSCF (thousand standard cubic feet) per 100 statute miles on the same basis

as the lower estimates for crude oil and 2.6¢ per MSCF per 100 statute miles on the same basis as the higher estimates. The 4.5¢ per U.S. gallon fuel allowance in the crude oil case would be equivalent to about 30¢ per MSCF for LNG fuel for the airplane.

Of course, once the natural gas is liquefied, perhaps it should be carried farther - maybe even to the city gate markets. Fifteen or sixteen airplanes might deliver 3 billion (10^9) SCFD over an air distance of 1000 nautical miles (1150 statute miles). Per-mile costs would be slightly lower, and the lower and higher estimates previously mentioned would become approximately 1.7¢ and 1.9¢ per MSCF per 100 statute miles for this longer distance.

APPLICATION OF THE PRESENT CONCEPT

If further study and development should confirm the present cost estimates, then airlift might offer a very attractive alternative way to move Arctic resources, especially from the islands north of the Parry Channel. If further study reveals a serious flaw in the concept or the estimates, development of ice-breaking tankers or of the pipeline technology necessary to cross the deep Arctic channels would be more clearly justified. Let us examine some of the possibilities should the economic feasibility be substantiated.

We are still firm in our belief in the following simple concept: an airplane can fly in almost any part of the world at a ton-mile cost determined basically by the airplane's load factor and design. Even the most adverse ground conditions only raise the cost by some infinitesimal amount. It doesn't cost any more to fly over mountains or ice than over the home field. Ground transportation costs, however, tend to vary with location.

COMPARISONS

Ground transportation systems in the north fight the environment every foot of the way. A foot of progress across prairie fields and meadows costs significantly less than a foot across muskeg. A foot of progress across discontinuous permafrost costs still more, and a foot through hard, frozen, water-saturated moraine costs much more. Mountains, river crossings, active seismic zones and lengthening supply lines increase such costs, and crossing a broad deep sea channel in the high Arctic may be in a totally different cost class than progress across the prairie farmland. Similar comparisons can be drawn between ships in the South Atlantic and ships in McClure Straight, or between railroads in the Ottawa Valley and railroads crossing a Brooks Range pass.

Perhaps the cost curves for airlift and ground transportation cross at some point. If they do, we might improve total transportation economics by flying the cargo over that part of a route where airlift appears cheaper and moving the cargo on the surface when that becomes cheaper. The idea is shown by Figure 8, which only illustrates the concept and is not plotted to scale. Cost per mile increases vertically and the horizontal axis implies a range of conditions from temperate zones on the left to polar regions on the right. The solid line suggests trends in the cost of surface movement of cargo and the dotted line suggests the more constant cost of airlift. The portions in heavy lines suggest what might be the most economical way to ship considering the total cost of transportation. It includes a transfer from air to surface (southbound) in the neighborhood of the circle about midway across the horizontal scale. The transfer could be made cheaply with a fluid cargo such as crude.

Gross differences in approach and technology compounded by differences in accounting practices, combined with the effects of government regulations and the widely recognized uncertainties facing all Arctic operations, make it difficult to agree where, if at all, the cost curves cross in a given case or if either is the right shape.

Thus, in spite of tentative evidence that the curves do cross, in many cases it is difficult to prove the advantages of airlift over any single surface transportation link for large volume bulk cargos in the Arctic.

THE DEVELOPING ARCTIC SITUATION

As the real situation has developed, however, we are faced with a far different question. Should we consider a flexible, incrementally expanded airlift system as a trade or alternative for a less flexible network or a complex of multiple surface modes?

In the case of a single large oil strike with a large volume of associated gas, two separate pipelines are required, perhaps by different routes to different markets. Conceivably a large volume of propane could still have no way to market. This alone puts airlift and pipelining on a comparable total investment basis. As more strikes are made, the situation becomes more complicated. It would seem that the combination of the widely separated new reservoirs and dispersed markets might eventually cause a great deal of pipeline to be built.

THE AIRLIFT CASE

For any new oil field, airplanes could be produced at a rate which matches the transportation

capability with the available flow resulting from orderly field development. The terminals or airports could start with simple, single runways and expand later to accommodate increases in traffic.

The full investment would not be made until full capacity was reached and initial operations would be somewhat less efficient than operations at capacity. In sharp contrast to the Arctic crude pipeline case for a new discovery, however, capital investment growth in the airlift system could much more nearly match system capacity and revenue at any point in time. Such a pipeline would generally require almost the total investment before the first hydrocarbons could move. In the airlift case, the capital investment for more than half of the ground installations and almost all of the airplanes could be withheld to avoid interest charges or delayed until needed as orderly field development justified increased flows.

To initiate shipment of associated gas, additional capital investment would be required for a single train liquefaction plant and additional airplanes. Growth in capacity eventually might require additional liquefaction and expansion of both north and south terminals, as well as more airplanes. To open production at a second field some distance from the first, the initial capital investment would be only for a minimum terminal near the field and additional airplanes produced at a rate to match field development until traffic saturation required expansion of the southern terminal. Service to a second market could similarly start with a minimal investment.

Once an airlift system started operation, interesting additional opportunities might develop. For example, a mine that could generate only one airplane load per day might obtain economical transportation with a minimum investment in two or three sets of special containers, one set of loaders, and a simple runway.

A SPECIFIC EXAMPLE

As a specific example of an airlift system development concept, we might visualize a destination terminal near the end of existing pipeline right of way south of Great Slave Lake. This terminal could receive oil and LNG airlifted from the Mackenzie Delta Region as a short-range example and LNG from the Ellef Ringnes-King Christian Region as a long-range example. Both routes would be along the shortest or airline distance, of course. Even at the present point in exploration, it would appear that just these two regions together might justify development of a system with a sophisticated southern terminal.

If the new deep water port proposed by the Canadian group that has worked with us should be developed in Hudson Bay near the mouth of Chesterfield Inlet, a receiving terminal near the new port might be a very attractive alternative to the Great Slave Region. Of course, by the time decisions are made, it might be preferable to build the new Chesterfield Inlet port terminal first, even for Mackenzie Delta oil and gas. Such a port could handle supertankers, perhaps on a year-round basis. If exploration continues to be as successful as it has been during the last few years, perhaps fully developed destination terminals could be justified at both locations. This, of course, is merely one of many possible situations and is intended to illustrate a principle.

POTENTIAL BENEFITS OF AIRLIFT

FLEXIBILITY

Consideration of a system developed to such a degree begins to show the potential benefits of airlift flexibility. The relative amounts of crude and LNG delivered to the two southern ports could be shifted slowly or rapidly to accommodate shifts in markets and competitive pressures. The relative amounts could even be shifted to some degree overnight to help counter national or international emergencies or the impact of some major disaster.

Should long range trends dictate a shift of the total output from one terminal to the other, almost an entire terminal except the runways themselves could be shifted to expand the remaining terminal if modular construction is used to best advantage in the final designs.

It is interesting to speculate on the many such possibilities but it may be more useful to compare a shift such as the one described above with a comparable situation for a conventional transportation mode.

DIVISIBILITY

In economic terms, pipelines and railroads are indivisible resources to a large degree. Capacity can be varied up to some maximum feasible limit and a small part of the total investment can be delayed until the maximum capacity is needed, but no part of the basic system can be split off or diverted although branches can be added. Rapid shifting or rearrangement of capacity and capital equipment is not feasible technically or economically.

Pipeline and railroad both suffer additional loss in flexibility, because so much of the capital

investment is involved in the right-of-way and preparation of the right-of-way. Assurance of a large long-lived reservoir is required to make this right-of-way investment feasible. A much smaller individual reservoir would be required for any one part of an airlift system so long as other reservoirs were available.

The many small settlements that often develop along land surface routes create potentially serious human and economic problems if route abandonment has to be considered. Another way to look at this aspect of the problem is to consider the relative salvage or alternate use value of the systems in the event of unforeseen early depletion of a reservoir.

ENVIRONMENT

We are not among those who are fearful about the inherent safety of ground transportation modes. Those active in various environmental protection organizations insist, however, that studies of potential environmental damage be made in connection with any major new proposals these days. A much quoted evaluation is in a pioneering paper by two University of Toronto economists*. They present the concept of expected pollution costs based on magnitude and frequency of spills. Their estimates of the cost of cleaning up spills show the airlift system to be lower than the pipeline by a factor of 20 and lower than a railroad scheme by a factor of 2 1/2. Expected frequency of spills, however, tends to even out these costs in their view. Since their paper was prepared, Alyeska Pipeline Service Company has made engineering changes which show it is possible to reduce potential spill volumes substantially and their assumed airplane accident rate is nearly three times that of commercial jet experience. Much more study is indicated.

Two other environmental impacts are primarily associated with airplanes in the public mind: noise and engine exhaust. Even if no further improvements are made in the engine or its installation, it appears that a twelve-engine airplane can pass the current U.S. Federal regulation for new commercial jets. Visible smoke is already being eliminated on commercial jets and exhaust problems will be almost entirely eliminated if methane is used for fuel.

The environmental problems usually associated with the Arctic ground systems including damaged permafrost, disruption of wildlife and damage to fisheries appear to us to be solvable although the costs of solutions fully satisfactory to environmental activists may still be in considerable doubt.

Ground facilities are also required for an airlift, of course, but each 12,000 foot by 400 foot runway is only 110 acres. Perhaps this size is small enough to plan for comprehensive restoration and consider it as a cost of abandonment.

STRATEGIC IMPLICATIONS

Total strategic implications involve too many imponderables to attempt full analysis here. Two specific points do deserve some comment, however.

Arguments about the most vulnerable points in various systems are common but generally fruitless. So are arguments about absolute invulnerability. A more realistic issue is assessing the cost of protecting an entire system against some credible threat or danger. Successfully guarding the entire length of a long ground transportation link for a significant interval of time at any cost has been shown many times to be almost impossible. Pipelines at or near the surface and trains are notoriously vulnerable, even to casual vandalism.

The second point concerns reaction in case the transportation system is disrupted in spite of precautions. If, for example, the complementary pipeline or marine tanker portion of an airlift system should be destroyed, either by natural disaster or by human interference, the airplanes could haul cargos the full distance to markets at slightly reduced capacity and increased cost. In fact, the airplanes could deliver cargo to any critical point which might be isolated from its normal supply.

The national benefits of having a potentially less vulnerable system are obvious but perhaps impossible to quantify.

GROWTH POTENTIAL

Though not potentially a direct benefit to the petroleum industry of Canada, the growth of an airlift system based on these concepts and operating in the cost ranges discussed could have an impact on many shippers and on many existing transportation systems. Such growth or expansion could conceivably be immensely profitable to all those with an equity position in the system development.

One example of the kind of mission that might be flown by some of the airplanes in an expanded system might be called a multi-route mission. This mission would be quite different from the high-capacity resources missions. The airplane or airplanes would fly various routings but would do so for specific loads contracted for far in advance and each round trip would be similar though perhaps

different in some details.

One plane might pick up 1,000 tons of iron ore from Baffin Island and carry it to the new port near Chesterfield Inlet in Hudson Bay. At the new port, it would pick up 1,000 tons of mixed containerized cargo and fly it perhaps to northern Alberta to supply, say, a tar sands construction project there. Then it would fly empty to the Yukon mining region and pick up, for instance, 1,000 tons of asbestos for delivery to Prince Rupert. At Prince Rupert the airplane would pick up 1,000 tons of containerized cargo from freighters that can't use Panama and fly direct to the new port for transshipment to Europe. From the new port, fly empty to Baffin to start the cycle over. One airplane might be able to fly such a mission between two and three times per 24 hour day.

A great deal of analysis will be required to find a large number of realistic missions with favorable economics but once the multi-mode mission is recognized, the possibilities seem almost endless. Interestingly enough, many of the potential resources of the world are inland in the continents having relatively undeveloped transportation systems -- Africa, Australia, South America, Asia.

PROGRAM STATUS

As of the end of March of 1972, it appears that if our initial conceptual designs and preliminary economic estimates can be verified, airlift could offer an attractive alternative to pipelines in moving resources out of the Arctic islands and perhaps out of the northern mainland as well. The preliminary figures have been extensively reviewed by experts in many fields without new questions being raised or gross errors being discovered. The preliminary figures are attractive enough to warrant an in-depth study to fully define the system and calculate accurate costs per ton mile so economic feasibility can be judged by all potential shippers.

In the total study effort to date, no requirement for new technology development has been identified. Although clearly within the limits of existing technology, the costs of solving some of the evident problems such as those with the Arctic environment, airplane structural dynamics and the high airplane utilization rates are uncertain.

Before any reliable determination of economic feasibility can be made, it is necessary that every element of the system, the airplanes, the terminals, the cargo handling system, the maintenance and logistics system, and the management and operation system, be carefully defined through in-depth engineering and analysis.

Before these things can be firmly defined, there are many questions and issues that must be resolved. The airplane and system configuration have to be compared to alternatives and the best combination selected. Aerodynamic models must be flown in wind tunnels to verify performance, air loads, stability and control. Flutter models must be flown in wind tunnels to develop and verify solutions to any potential problems with structural dynamics. Analyses and simulations of landing dynamics will also be required. Some research and testing may be required to verify systems to handle alternative fuels, including liquefied methane and propane. The reliability of every component must be reviewed, considering both the high utilizations needed and the environmental extremes expected. Terminal designs must be completed and site development plans worked out in detail.

After these and many other tasks have been completed, all of the hardware, the people and the software in the total system must be defined in detail and system operation simulated with some sophisticated applications of statistics. Only then can cost estimators be expected to produce trustworthy numbers. This has not yet been done, but such definition and feasibility study appears to be the next step.

A Canadian group is now raising the money to fund such a study. Some people are beginning to believe the Canadian Arctic Resources Air Transportation System will some day become a reality. A few people are becoming convinced it will be the preferred or even the only acceptable way to move resources in the Arctic.

SUMMARY

CONDITIONS FOR FEASIBLE RESOURCE AIRLIFT

- Plan the airlift of some resources for short hauls (1000 nautical miles or less) and use a ground mode of transportation as a complementary system.
- Achieve very high utilizations of all the expensive elements in the system through careful total system engineering and integration.
- Design an airplane system specifically for the job.

POTENTIAL AIRLIFT BENEFITS

- Avoiding most of the problems of crossing the Arctic surface.
- Avoiding the pipeline network problem.
- Avoiding the large very early or front-loaded investment required by Arctic oil pipelines.
- Offering a better chance of matching the capacity requirements of orderly field development.
- Assuring more flexibility to meet growth through new discoveries or unforeseen changes in reservoir or market.
- Having potentially less strategic vulnerability.
- Promising world-wide growth potential for a single non-recurring investment.

*The Economics of Oil Transportation in the Arctic by Q. D. Quirin and R. N. Wolff prepared for a conference on Canadian - U. S. Law of the Sea Problems - June 1971.

LARGE RESOURCE TRANSPORT AIRPLANE CONCEPT

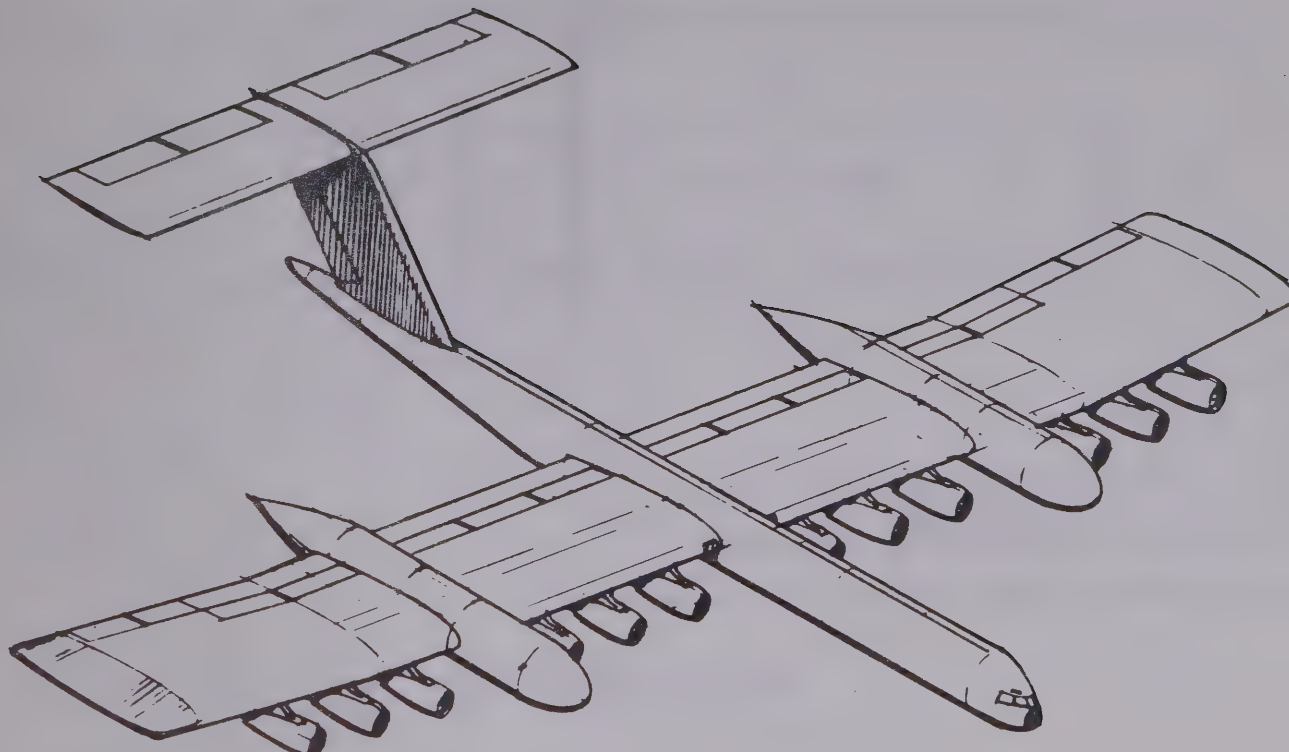

FIGURE 1

AIRCRAFT CONCEPT

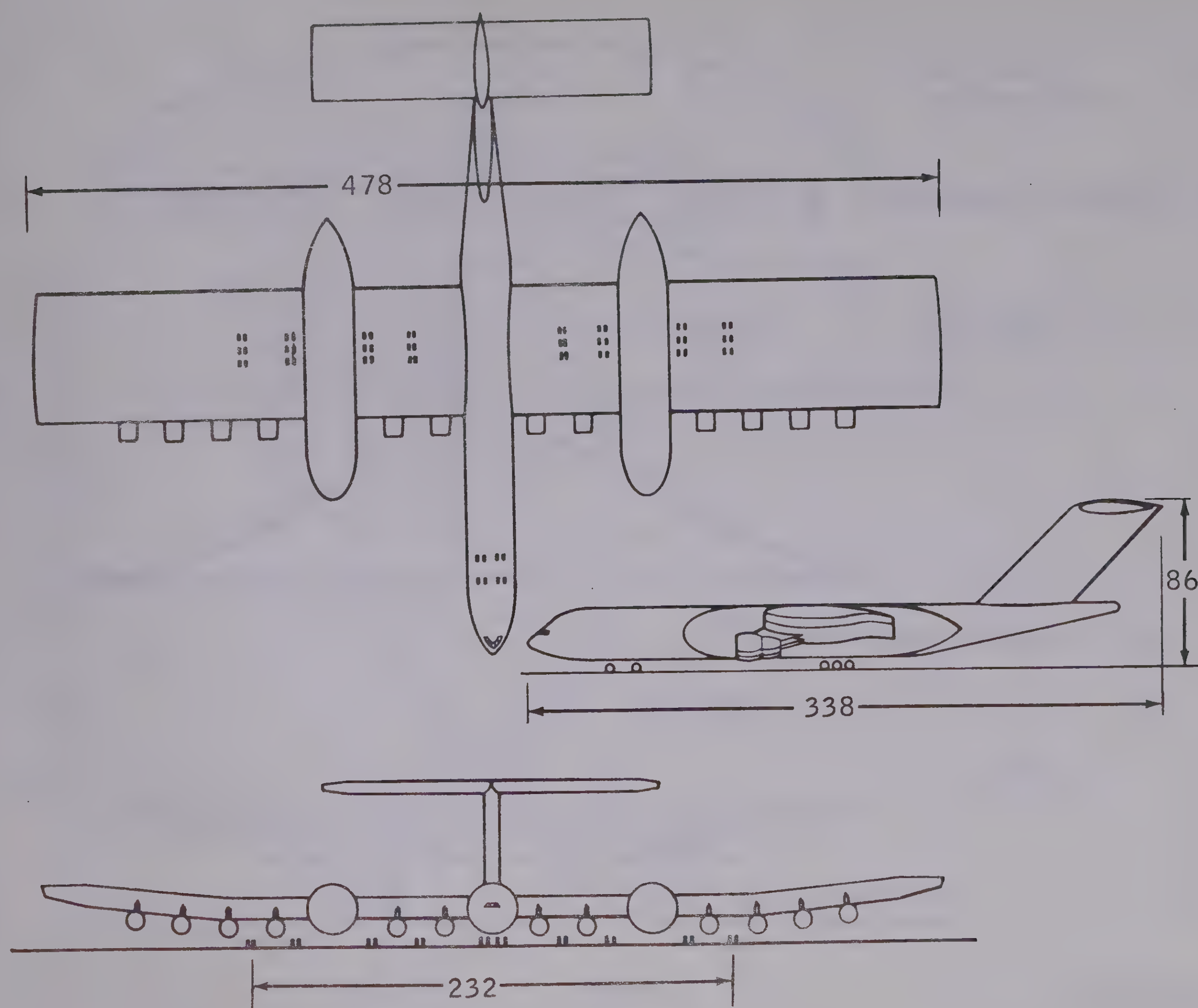

FIGURE 2

HIGH STRUCTURAL EFFICIENCY

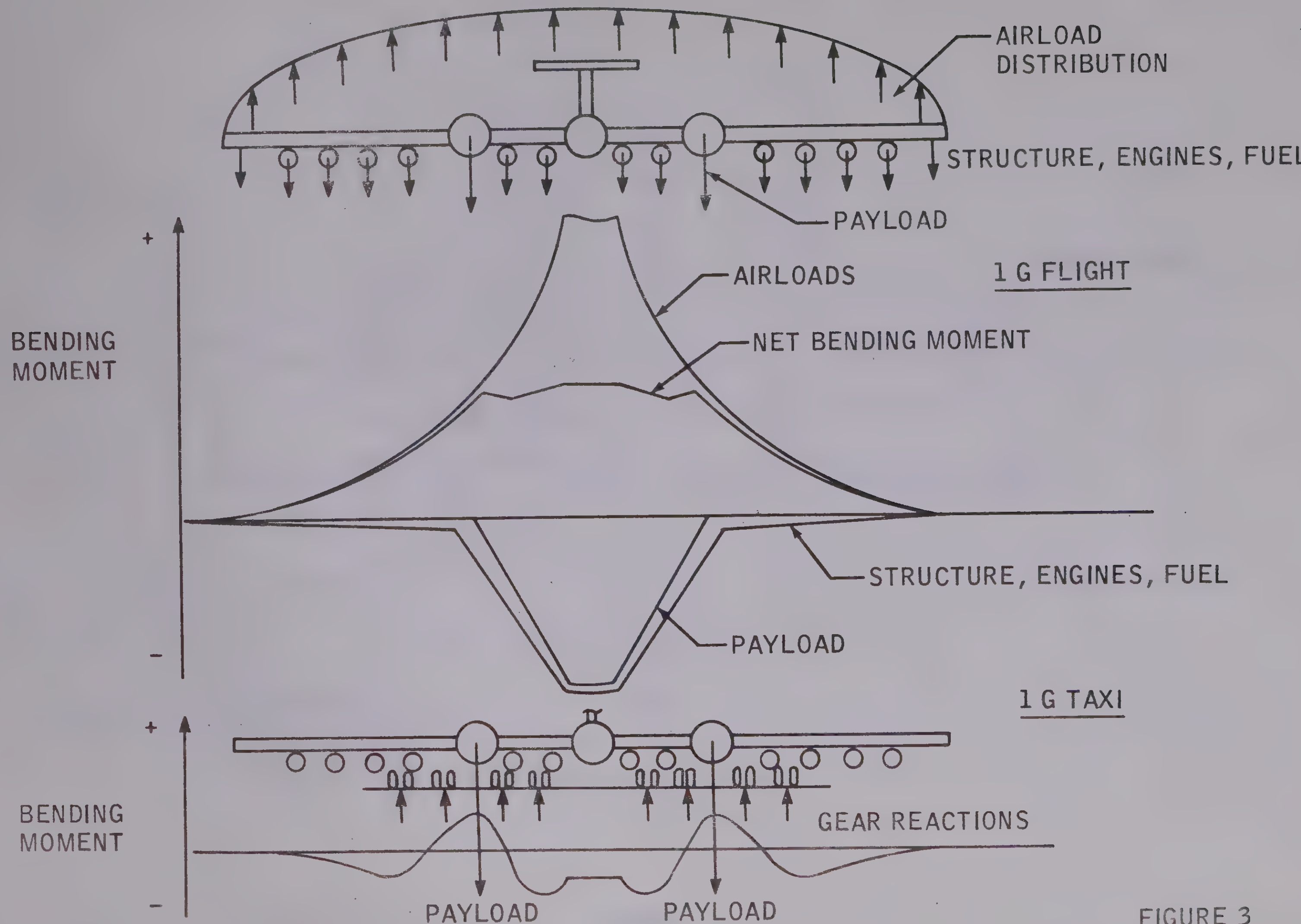

FIGURE 3

FLEXIBILITY, FAST TURNAROUND

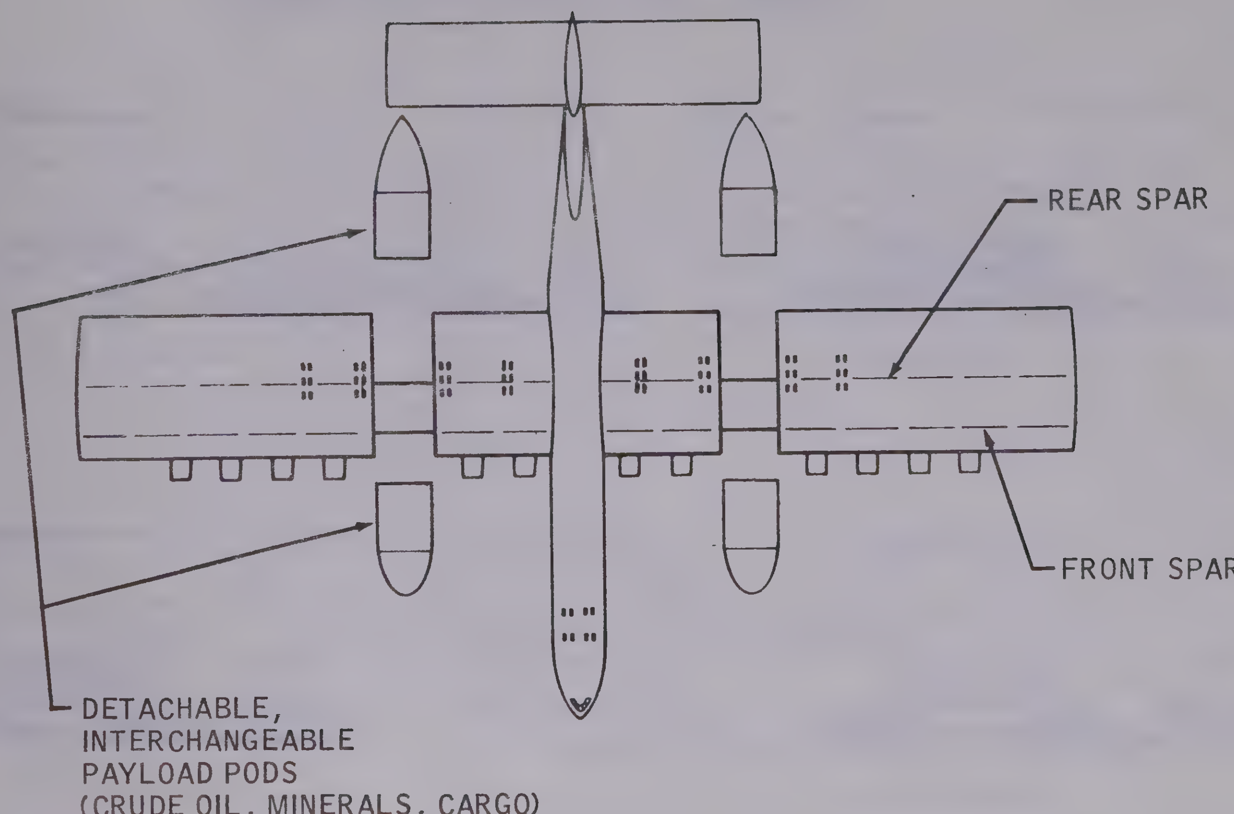

FIGURE 4

CONTAINER HANDLING CONCEPT

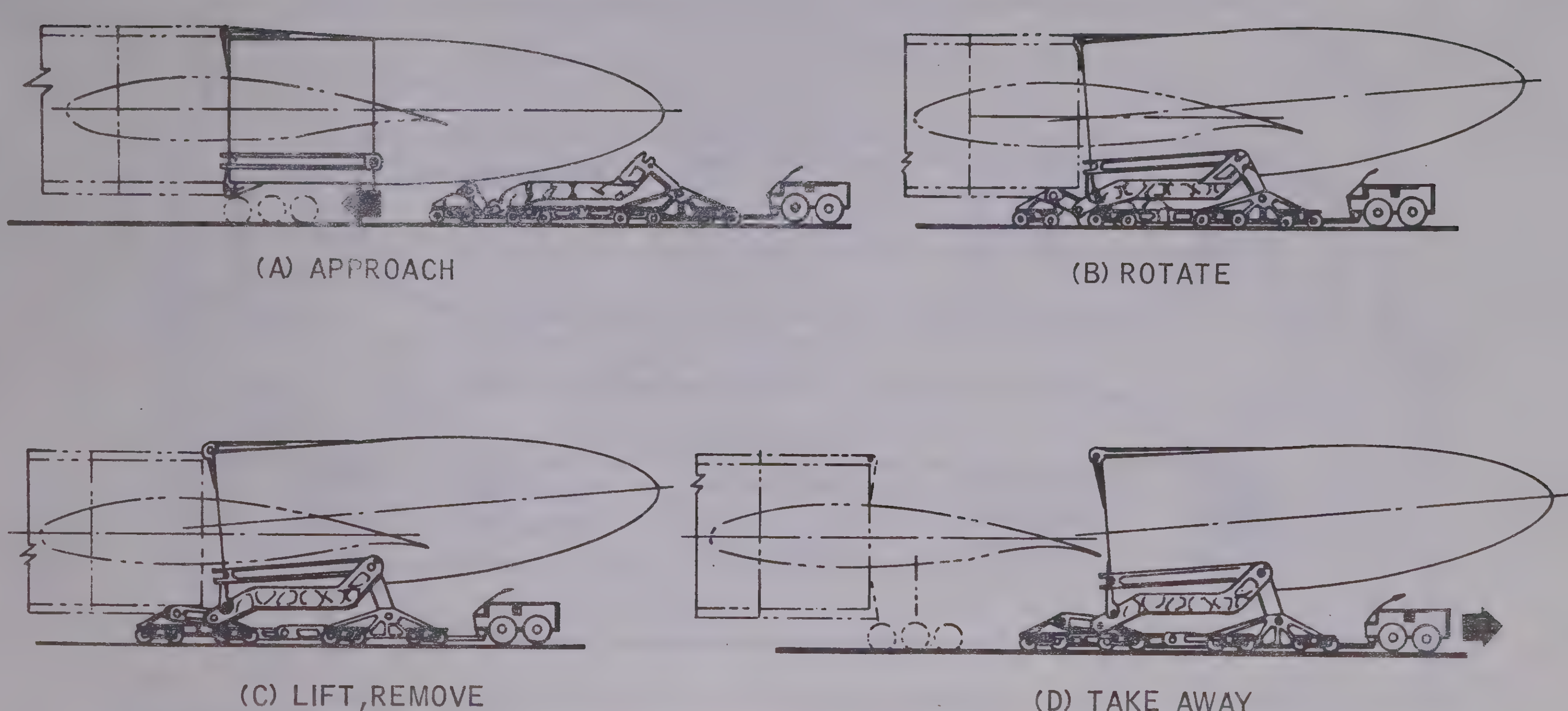

FIGURE 5

MAJOR TERMINAL

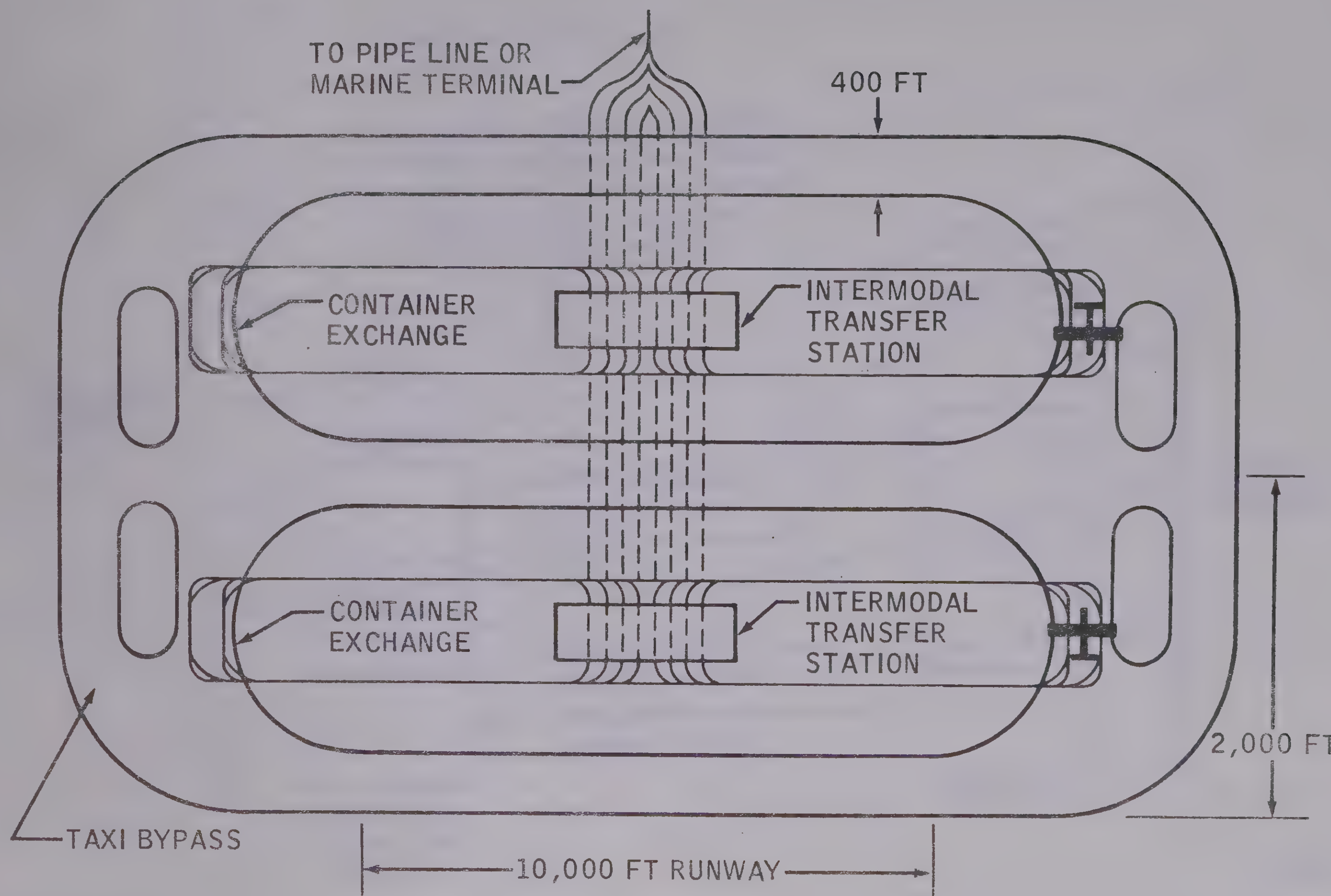

FIGURE 6

TRANSPORTATION COSTS

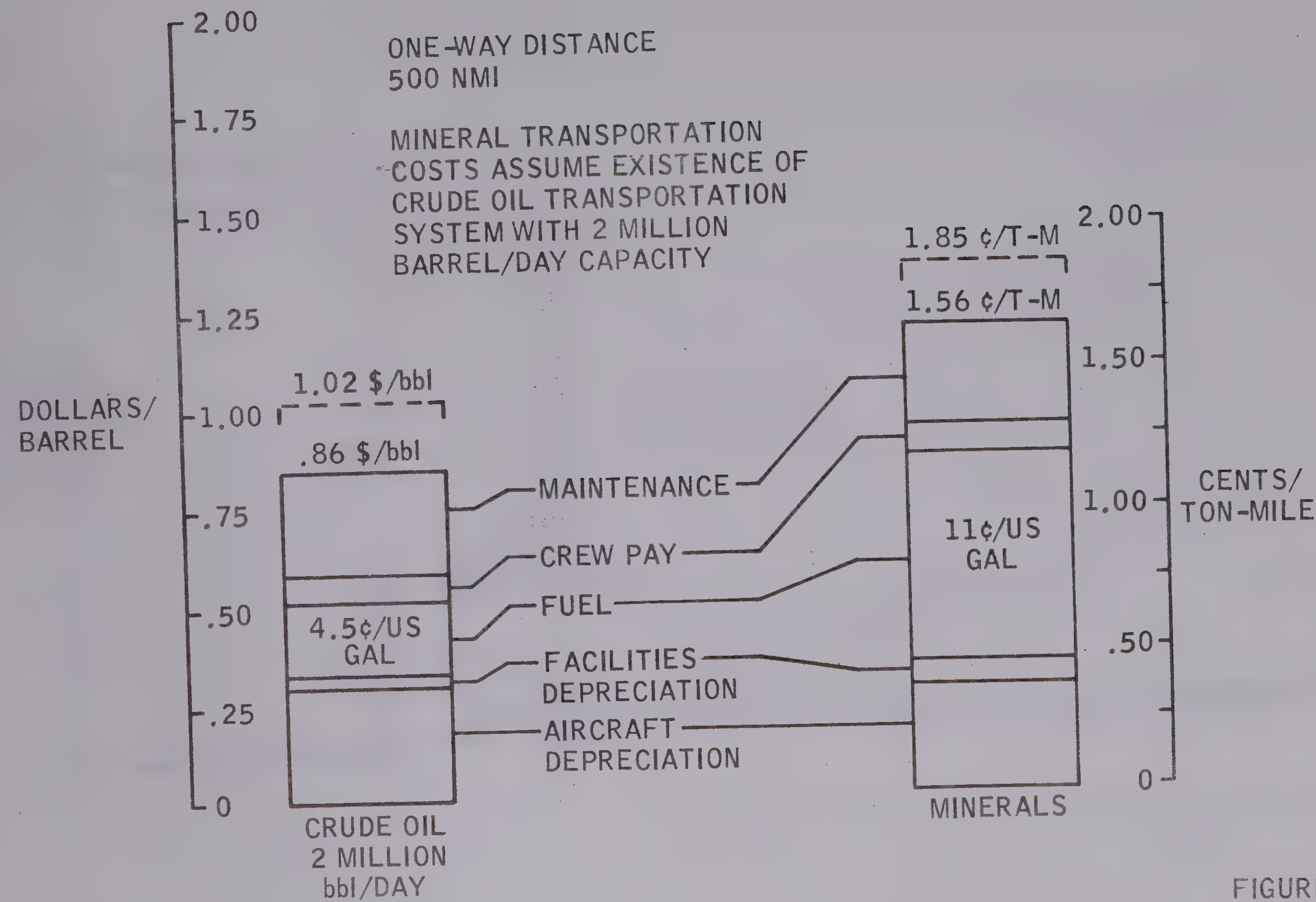

FIGURE 7

RELATIVE TRANSPORTATION COST

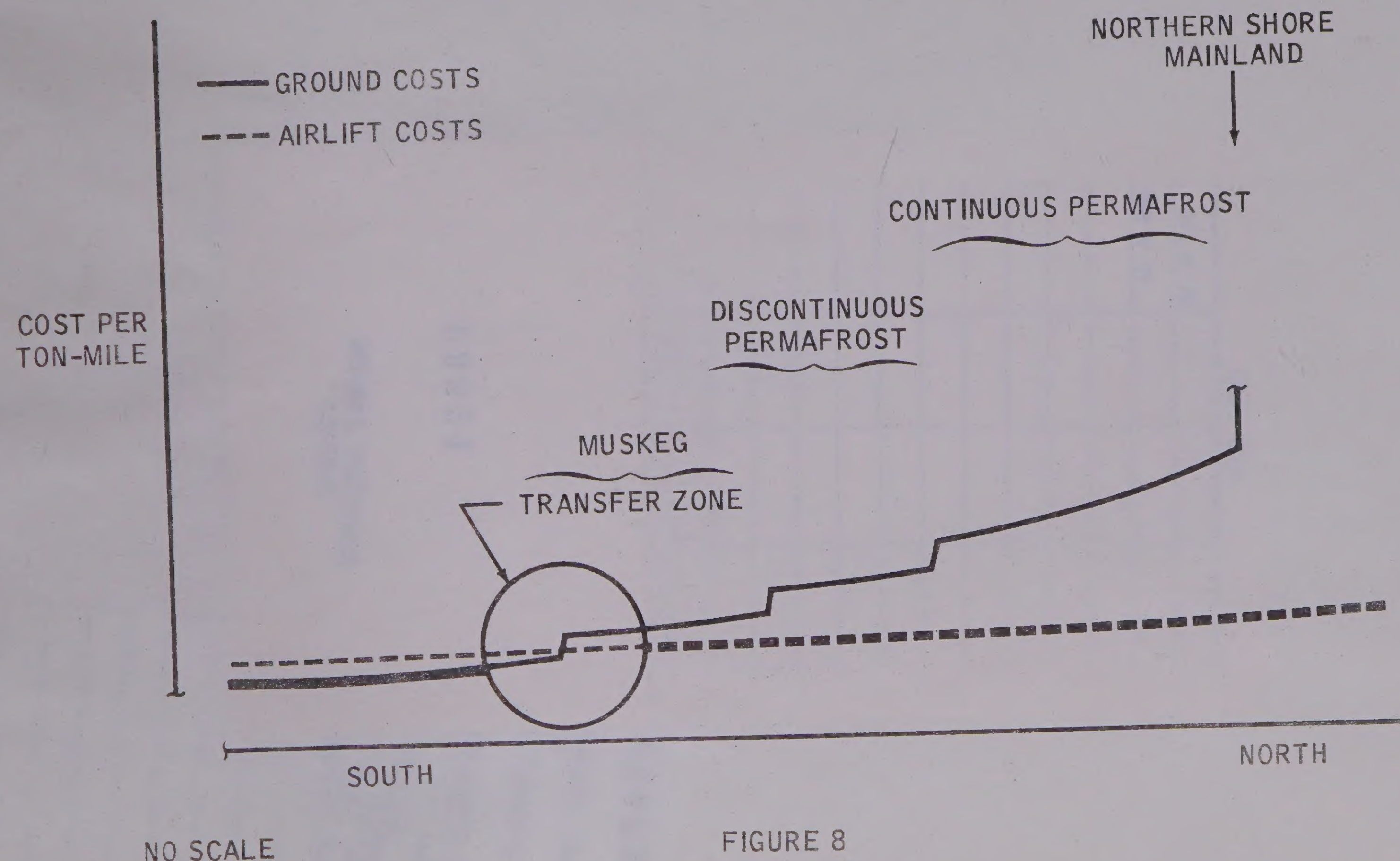

FIGURE 8